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Materials failure analysis utilizing rule-case based hybrid reasoning method

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ABSTRACT

Materials failure problems are becoming a serious concern because there would be a variety of consequences possibly affecting public safety. Therefore, materials failure analysis is needed to find out the reason of failure and avoid similar failures' reoccurring. However, materials failure cases mostly rely on manual analysis by experts with sufficient domain knowledge, leading to the situation of time-consuming, low efficiency and difficult evaluation. This paper proposes a rule-case based hybrid reasoning approach for materials failure analysis with the aid of ontology. Hundreds of materials failure cases from different industries were collected and analyzed by rule-based reasoning, case-based reasoning and our hybrid method. It is demonstrated that the rule-case based hybrid reasoning method can obviously provide better analysis results in comparison with rule-based reasoning and case-based reasoning alone.

1. Introduction

Failure analysis can be defined as a structured procedure that uses a process-based approach to find out failure components, materials and mechanisms. After the analyzing, it can conclude why the failure occurred rfailure reason) and which mechanism caused the failure (failure mode). The analysis result can also improve the design, operation and maintenance strategies for materials, thereby reducing the risk of failure and increasing service safety level. Traditional materials failure analysis relies on the brainstorming activities of experts in the field. The experts analyze the causes of failure based on the failure situation and the subsequent analysis data, and then give improvement measures and suggestions based on their experiences. The limitations are obvious: time-consuming, low efficiency, difficult evaluation (of the advantages and disadvantages of the analysis results), hard to share knowledge for reuse.

To reduce manual analysis work of domain experts by automation as a bridge between materials science and computer science is becoming a challenge in materials failure case analysis. Collaboration of computer science methodologies are still being needed to handle the relationship between failure cases and scientific experiments in materials failure analysis researches. Many scientists and engineers put forward different solutions. Graham-Jones et al. proposed an expert and knowledge-based system for failure analysis by case-based reasoning [1]. But it deeply relied on large amount of cases and was hard to be applied in wider domains due to the inflexible knowledge representation.. A tool name RODON was proposed to realize model-based failure analysis [2]. Unfortunately, its basis is to establish complete models of failure mode before application, which brought hard manual work. With the development of artificial intelligence in recent years, some researchers have tried to solve the problem by reasoning methods. The reasoning

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methods applicable to materials failure analysis mainly include rule-based reasoning and case-based reasoning. The concept of rule-based reasoning is based on domain expert knowledge and empirical reasoning, which abstracts the knowledge and experience of experts into rules in a number of reasoning processes [3]. In case-based reasoning, the basic idea is to solve the problem in the process and the decision-makers have to fully use the past failure case experience to solve new problems [4]. The use of similarity to find the past empirical model can be used as a solution for a new problem. Peng Shi et al. studied the knowledge sharing of materials failure analysis, constructed the ontology knowledge-based model of materials failure cases, and explored the preliminary use of rule-based reasoning in materials failure analysis [5]. The advantage is more intuitive, easy to understand the reasoning process and the efficiency of reasoning is relatively high; but its success is based on the establishment of all relevant knowledge and reasoning rules. Unfortunately, the complex rules and conditions are difficult to achieve. Amen and Vomacka described a materials selection method based on case-based reasoning, and applied case-based reasoning technology to materials selection, fault analysis and so on [6]. The advantage is that there is no need for explicit domain knowledge model, which avoids the bottleneck of knowledge acquisition. Incremental learning makes the coverage of the case library to be increased gradually with the system and gradually improve the system. However, the shortcoming is that it cannot cover all solution space. The optimal solution may be missed.

In order to utilize the advantages of the two methods, Rissland et al. proposed a heuristic approach (that is, an approach that can find the optimum solution more quickly than classic approaches by themselves or conjunction of optimization algorithms) that combines rule-based reasoning and case-based reasoning and discussed the feasibility of the method [7]. It is still a framework and needs to be implemented and verified in different areas.

In this paper, three reasoning methods (rule-based reasoning, case-based reasoning and rule-case based hybrid reasoning) were implemented and analyzed with comparison by using a total data of 318 cases from six industries (i.e., transportation, nuclear power industry, electricity power industry, oceanographic industry, oil and petrochemical and aerospace). Data were mainly collected from papers and monographs, as well as materials failure reports. A rule-case based hybrid reasoning approach for materials failure analysis was proposed. Ontology can solve the problem of sharing and reusing of knowledge by constructing the rules of materials failure to form the knowledge map of materials failure field. The hybrid method firstly collects and summarizes the cases of materials failure and uses the ontology to construct the rules of materials failure to form the knowledge map of materials failure field [8]. Then, the cooperative reasoning mechanism of rule-based reasoning and case-based reasoning is proposed, and an evaluation standard is given to evaluate the analysis result objectively. The results of hybrid reasoning method are quantitatively analyzed and compared with both simple rule-based reasoning and case-based reasoning methods. It can be seen that the hybrid method can achieve better analysis results and realize the knowledge accumulation and automation case analysis.

2. Models and algorithms

The core idea of this paper is to solve the problem of materials failure analysis by collaborating rule-based reasoning and case-based reasoning. The premise of rule-based reasoning is to construct inference rules, implement those rules for construction of ontology, and then determine the model and algorithm of rule-based reasoning. Case-based reasoning is used to construct the complete and effective case set, and then determine the model and algorithm of reasoning. Hybrid reasoning, the combination of rule-based reasoning and case-based reasoning, is effectively used with the advantages of two methods to develop automatic knowledge sharing system. The following will introduce the models and algorithms used in this paper.

2.1. Ontology

2.1.1. Ontology introduction

Ontology is a concept to acquire the domain knowledge when developing the knowledge system. Ontology was originally a philosophical concept used to describe the nature things. Later, the knowledge engineering scholars borrowed the concept and used it to acquire the domain knowledge when developing the knowledge system. Ontology can reduce or eliminate the confusion between domain concepts and terminology, and become the foundation of communication, sharing and interoperation between systems. Therefore, it can solve the problem of sharing and reusing of knowledge.

2.1.2. Ontology representation language

OWL, Web Ontology Language, is a kind of network ontology language developed by W3C (World Wide Web Consortium), which is used to verify the consistency of knowledge or make implicit knowledge explicit [9]. OWL has greater machine interpretability of web content than other semantic web languages, such as XML (Extensible Markup Language), RDF (Resource Description Framework) and RDFS (RDF Schema). It has the ability to express not only more powerful semantics but also the Description Logic (DL) reasoning. W3C has designed three increasingly-expressive sublanguages of OWL, regarding the need of all kinds of features, namely, OWL Lite sub language, OWL DL and OWL Full.

2.1.3. Building the ontology of OWL

Through the analysis of the collected materials failure cases, an entity *Failure Case* can be firstly defined, which includes several attributes such as Name, Industry, Tags, Description, Appearance, Environment, Component, Materials, Mode, Affect, Reason, Conclusion and Suggestions, and Industry, Component, Materials and Mode in the attributes can also be defined as an entity to analyze [5]. In order to distinguish between entities and attributes, Case's prefix is added to the attributes of the case. Entity *Failure Case* includes attributes *CaseName, CaseIndustry, CaseTag, CaseDescription, CaseAppearance, CaseEnvironment, CaseComponent,*